UNIV. OF MICHIGAN
MAY 20 1953
EAST ENGINEERING LIBRARY

*Volume 39* May, 1953 *Number 5*

TJ
1075
A2
L92

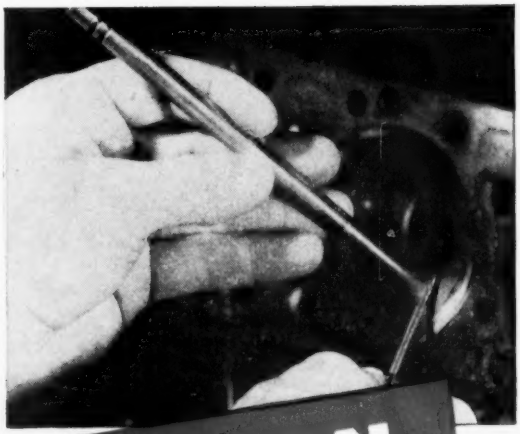
# Lubrication

## A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

AUTOMOTIVE
ENGINE
BEARINGS

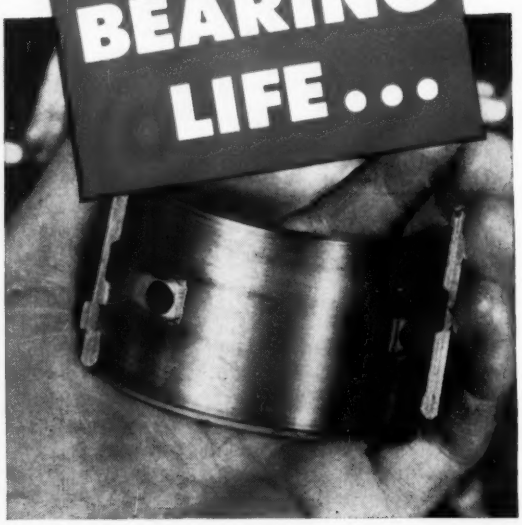
PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS



**FREE RINGS**

**CLEAN VALVES**

**LONGER BEARING LIFE...**



## when you use TEXACO D-303 MOTOR OIL

TEXACO D-303 MOTOR OIL is fully detergent and dispersive . . . cleans as it lubricates . . . holds deposit-forming materials in harmless suspension between regular drains. All rings thus stay free for proper compression, assuring full power and fuel economy.

Valves stay clean, too. With *Texaco D-303 Motor Oil* you'll have fewer valve grinding jobs, gain many extra miles of trouble-free operation. And special additives in *Texaco D-303 Motor Oil* protect bearings from corrosion, help reduce wear, prolong life. In sum, you can count on *Texaco D-303 Motor Oil* to reduce maintenance costs and fuel consumption for both heavy duty gasoline and Diesel engines.

Let a Texaco Lubrication Engineer show you the many advantages and economies of Texaco effective lubrication. Just call the nearest of the more than 2,000 Texaco Distributing Plants in the 48 States, or write The Texas Company, 135 East 42nd Street, New York 17, N. Y.

TEXACO REG T M

**TEXACO Lubricants and Fuels**

FOR THE TRUCKING INDUSTRY

# LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

Published by
The Texas Company, 135 East 42nd Street, New York 17, N. Y.

Copyright 1953 by The Texas Company
Copyright under International Copyright Convention. All Rights Reserved under Pan-American Copyright Convention.

J. S. Leach, Chairman of the Board of Directors; A. C. Long, President; R. F. Baker, Executive Vice President; G. R. Bryant, E. R. Filley, M. Halpern, A. N. Lilley, L. H. Lindeman, A. M. Ottignon, J. H. Pipkin, R. L. Saunders, Torrey H. Webb, J. T. Wood, Jr., Vice Presidents; Oscar John Dorwin, Vice President and General Counsel; J. W. Foley, Vice President and Assistant to the Chairman of the Board of Directors; W. G. Elicker, Secretary; Robert Fisher, Treasurer; E. C. Breeding, Comptroller.

Vol. XXXIX May, 1953 No. 5

*Change of Address:* In reporting change of address kindly give both old and new addresses.
*"The contents of 'LUBRICATION' are copyrighted and cannot be reprinted by other publications without written approval and then only provided the article is quoted exactly and credit given to THE TEXAS COMPANY."*

# AUTOMOTIVE ENGINE BEARINGS

TO MANY who remember the early days of the automobile the cry "Get a horse!" recalls pleasant memories while to others, it envisions the all-too-frequent towing home of the horseless carriage. Since that period at the turn of the century, the automobile has thrived to the extent that today a horse is a rarity that commands attention. Much credit for the development and advance of the automobile is due to the "engineuity" of self-trained mechanics and to a public receptive to their product. That a demand existed is amazing when it is realized that automobiling was an adventure for the hardy.

Advances in automotive development have resulted in improvements in comfort and performance that defy description. In the last twenty-five years, average engine horsepower has more than doubled, compression ratios have climbed continuously upwards and cruising speeds have increased greatly. All this has been accomplished with no increase in engine displacement or significant change in car weight. The dependability of today's vehicles has made it possible for a family to take an automobile vacation that will cover both the Atlantic and Pacific seaboards in a few weeks' time; trucks are now hauling enormous loads and farm tractors have eliminated horse-drawn equipment. The virtual elimination of mechanical breakdowns—disregarding those produced by the human element—has been due to the continuous improvement in the constituent parts of the vehicle. Engine bearing design and development have made parallel gains.

Main and connecting-rod bearings for the early engines were of babbitt metal cast directly into the saddles, which were an integral part of the engine block, and caps. The bearing linings were thick and were bored to size in the finished assembly. These bearings had many drawbacks when compared with modern design. Production and assembly were slow and difficulties were experienced in securing good adherence or bond between the babbitt and the backing metal. The poor bond was due in part to the impossibility of properly cleaning and heating the engine blocks before casting. These bearings were of low fatigue strength and sensitive to wiping. When bearing failure occurred some mechanics are credited with making temporary field repairs by inserting pieces of leather belting in the bearing housing. This situation was remedied in the early twenties by the introduction of insert main bearings which were first supplied with babbitt linings on bronze backs and later on steel. To circumvent the hazards of poor bonding, elaborate dovetail grooves were cut in the backing metal to provide an anchor for the babbitt. The need for dovetailing later disappeared as improved bonding techniques produced a chemical union of the metals.

The engine designer's demand for higher speeds and increased bearing loads has required a number of bearing improvements. One line of endeavor

involved the introduction of alloys of greater strength than babbitt. Other efforts have produced extremely thin babbitt linings well bonded to the backing metal which have greater strength than that of the lining metal alone. Coupled with these developments has been the use of continuous manufacturing processes that form bearings to precise dimensions literally "by the yard."

## PROPERTIES REQUIRED OF A BEARING METAL

Bearing research and development has produced many alloys to supplement the long-accepted babbitt. In order to appreciate the advantages offered by the newer metals consideration must be given to those properties that are essential to good bearing performance.

1. The bearing metal must have antifrictional or surface characteristics which may be defined as follows:

*Anti-seizure*—The bearing metal should not have an affinity for the journal. If an affinity exists, welding and galling may result whenever momentary metal-to-metal contact occurs.

*Conformability*—The bearing metal should be sufficiently plastic to tolerate slight misalignment and adjust to such conditions.

*Embeddability*—The metal should be sufficiently soft so that hard particles, which gain access to the clearance space between the bearing and journal, may be engulfed within the bearing surface.

2. The metal must have sufficient physical strength to carry the maximum applied load. The finest antifrictional properties would be of little value if the metal were weak. The strength requirements include:

*Load Carrying Capacity*—The metal must have sufficient strength to carry the load imposed.

*Fatigue Strength*—The bearing metal must be able to endure repetitive poundings to which it will be subjected in the internal combustion engine. These forces are often in excess of the anticipated loading due to unforeseen stresses that may result from crankshaft unbalance, whip or vibration.

*Impact and Compressive Strength*—The bearing metal must be able to resist both deformation and plastic flow under shock load.

*High-Temperature Strength*—The metal should not lose strength excessively at high temperatures which may in some cases reach 275-300°F.

3. The following miscellaneous properties are also desired:

*Bondability*—The bearing metal must unite chemically with the metal that is employed as the bearing back.

*Corrosion Resistance* — The bearing metal should be of such composition that it will not be attacked by combustion products, by external contaminants that may have gained access to the lubricant or by those compounds that may have formed as the result of oil deterioration.

*Thermal Conductivity*—Bearing metals should have high thermal conductivity in order to carry away frictional heat from the bearing surface. This is especially important when momentary seizure occurs.

*Cost*—Bearing cost must not be excessive.

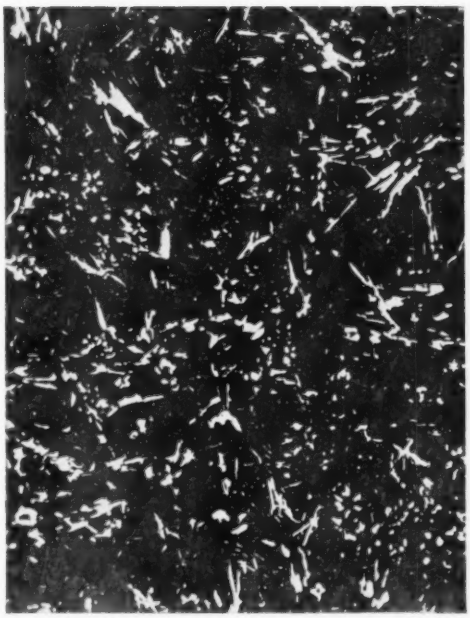
Consideration of the above requirements indicates that it would be impossible for any single bearing metal or alloy to excel in all of the desired properties. In fact, it is interesting to note that many of these items are at cross purposes. For example, the metal is required to resist plastic flow yet tolerate misalignment. The metal must be able to resist impact deformation yet be able to swallow foreign matter. These conflicts require the sacrifice of some properties. Automotive service generally considers high fatigue strength as the paramount bearing property although stop-and-go operation may place greater emphasis on antifrictional qualities.

As the perfect bearing metal has not yet been found, the selection of a bearing alloy must be a compromise where the desire for all of the properties is tempered by the actual needs of the application. Where compromise cannot be accepted, other means have been taken to circumvent the limits of the alloys as will be discussed.

## BEARING MATERIALS

At least five different basic materials and a number of alloy combinations are used as main and connecting-rod bearing linings in today's car, bus and truck engines. In all cases, the bearings selected for any application are in keeping with the loads and service to which the vehicle may normally be subjected. As these bearing metals differ in their properties it is of importance to know the advantages and limitations of each in order to obtain optimum bearing performance. If a bearing should not come up to expectations, consideration may be given to the selection of other materials, although it must be remembered that there may be no economy in going to heavier-duty bearings to correct malpractices. The heavy-duty bearings are generally more expensive than the babbitts due to the need for greater detail in manufacture and, in some cases, to the use of more expensive raw materials.

Relative costs of finished bearing inserts are listed in the following tabulation in order of increasing price.



Both views at 250 Magnifications

SAE-12 Tin-Base Babbitt showing the distribution of copper-tin needles in the matrix metal.
Nominal Analysis:
89% Tin, 7½% Antimony, 3½% Copper

SAE-14 Lead-Base Babbitt showing the distribution of antimony-tin cuboids.
Nominal Analysis:
75% Lead, 15% Antimony, 10% Tin

Figure 1 — Microstructures of white metal bearing alloys.

lead babbitt
tin babbitt
aluminum, steel-backed
copper-lead
copper-lead, overplated
cadmium alloy
aluminum, cast
silver, overplated

## White Metal Alloys

Some soft bearing metals are referred to as "white metals" because of their silvery color. In these, tin or lead is the major constituent and in no case are bearing metals of aluminum, cadmium or silver included in this category. The white metals are also known as babbitts in honor of Isaac Babbitt who, in 1839, was granted a patent on a bearing design that employed a pewter lining consisting of 89 per cent tin, 9 per cent antimony and 2 per cent copper, a composition very similar to those in popular use today.

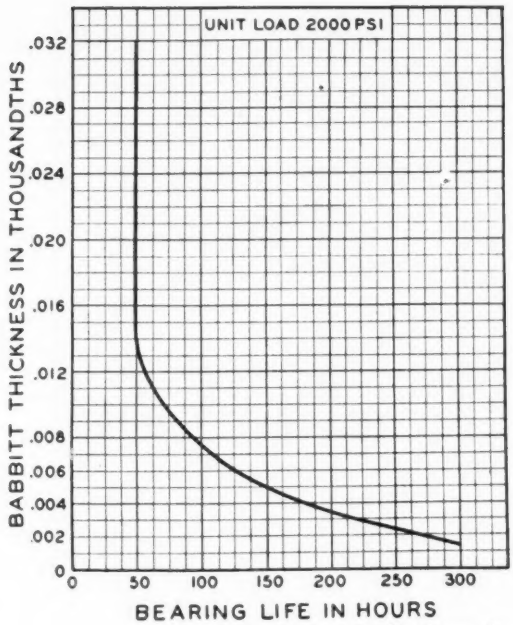
The white metals may be divided into two groups.

Tin-base babbitt
Lead-base babbitt

## Tin-Base Babbitt

White metals in which tin is the predominant metal have enjoyed an enviable reputation for many years and find service in countless applications. Long usage has resulted in numerous variations of the alloy composition employed by Babbitt. In general, these changes were made to alter strength, ductility or hardness of the alloy and, while of importance in specific services, they do not materially affect the properties of the group. In fact, the 1952 Handbook of the Society of Automotive Engineers lists only three compositions while many manufacturers supply a single alloy.

Tin by itself is too soft to be used as a bearing metal (Brinell Hardness at room temperature is 7) except in specialized cases; however, it is hardened by the addition of antimony and copper. Combinations of these metals produce extremely hard constituents that are present in the bearing alloy as distinct, recognizable particles as shown in both views of Figure 1. The microstructure of the alloy may be altered by changing the composition and/or the casting technique. Thus, if the antimony content is kept below 7½ per cent and the copper is present in excess of 1½ per cent, the metallographic structure will contain a network of copper-tin needles dispersed through the eutectic matrix—the eutectic being the lowest melting phase in the alloy. If the antimony content is greater than 7½ per cent, distinct cuboids will appear—their size and quantity being greatly affected by




*Courtesy of The Cleveland Graphite Bronze Co. Division of The Clevite Corp.*

Figure 2 — The Effect of Babbitt Thickness on Bearing Life.

the cooling rate. The presence of many cuboids and needles, both of which have hardnesses greater than 60 Brinell, will raise the alloy hardness to a maximum of approximately 30 Brinell with a corresponding loss in ductility. Reduction in size or complete elimination of the cuboids will soften the alloy.

In a tin-base babbitt, lead is a contaminant that lowers the softening point of the alloy, making it sensitive to wiping. Accordingly, the lead content is generally restricted to not more than 0.35 per cent. Reputable bearing suppliers adhere to this limitation but frequently, where bearings are being relined in small job shops, reclaimed babbitt of questionable composition may be used. Reclaimed metal may also be contaminated with abrasive bits of oxidized tin, the presence of which may account for otherwise unexplained shaft wear.

The excellent performance of tin babbitt is often ascribed to its heterogeneous structure i.e., hard particles supported in a soft yielding matrix. The hard particles provide a good, wear-resistant surface and, when embedded in a soft matrix, that surface can slightly deform or conform to the journal. By this action, a well-fitted bearing is created which can carry the load as well as embed any small foreign particles deleterious to normal bearing performance. Slight erosion of the matrix metal also provides a lubricant reservoir on the bearing surface. The aforementioned principle of bearing functioning does not hold for some of the newer bearing alloys that have only one basic micro-constituent as for example, the single phase found in silver bearings.

The exclusive use of tin babbitt has been limited for a number of reasons:

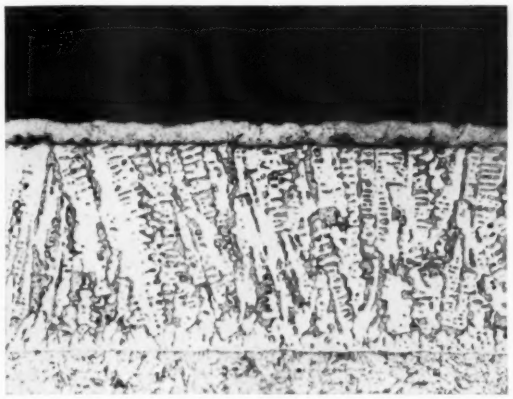
1. Its fatigue strength is a limiting factor.
2. The alloy rapidly loses hardness as its temperature is raised. For example, a tin alloy that has a room-temperature hardness of 24 Brinell will soften to 10 Brinell at 300 degrees F.
3. The tin metal is expensive and frequently in short supply.

## Lead-Base Babbitt

The lead-base, white metals have properties similar to the tin alloys. Unalloyed lead is softer than tin—having a Brinell hardness of four. This metal, unlike tin, is extremely sensitive to corrosion by certain organic acids that may form when a lubricant oxidizes. These short-comings are surmounted by the addition of antimony and tin as alloying metals. The antimony content usually ranges from 10 to 18 per cent (higher quantities produce a brittle alloy) with never more than 11 per cent of tin. Increasing the tin-to-lead ratio will reduce the strength and temperature qualities of the alloy and will produce a metal with the properties of solder. As with the tin babbitts, the alloying metals produce intermetallic constituents, the chief of which are the antimony-tin cuboids shown in the right-hand view of Figure 1. Small quantities of other elements such as silver, nickel or arsenic may be alloyed to improve the high-temperature strength and to reduce the tin content when that metal is in short supply. These addition elements also serve to improve the microstructure of the lead alloy. Although many variations of lead babbitt exist, the Society of Automotive Engineers lists three compositions and some manufacturers supply only one alloy.

Until recent years, lead alloys were reluctantly accepted as inferior substitutes for tin when the latter alloys were unobtainable. This aversion to the use of lead babbitts has been due to its slightly lower strength and to its greater sensitivity to corrosion, although both deficiencies have been minimized by suitable alloying.

The employment of new manufacturing techniques has improved the strength properties of both the tin and lead babbitts to equivalent levels. This has been accomplished by firmly bonding extremely thin linings of either tin or lead babbitt to steel shells. The strength of the resultant bearing is considerably greater than a thick layer of either babbitt metal alone. As shown in Figure 2, bearing strength is greatly influenced by the thickness of the lining metal. Tests have shown that lining



At 200 Magnifications

Figure 3 — Microstructure of a cast copper-lead bearing with white-metal overplate. The copper is white, the lead dark gray. The steel backing shows at the bottom. The white-metal surface coating is the narrow gray band across the top of the picture.

thicknesses of more than 0.014 inch have low life; halving the lining thickness under the same test conditions more than doubles the bearing life. This knowledge has been applied to today's automotive bearings where linings of 0.002 to 0.005 inch thickness are now being employed. As would be expected, the thin linings do not have the high embeddability and conformability properties that are present in the thicker linings.

This trend in bearing design may shock the power plant engineer who is accustomed to large tin-babbitt bearings that have linings in excess of one-eighth inch in thickness. Such bearings are conservative in design; subjected to low unit pressures, steady speeds and unvarying loads. In contrast, automotive bearing loads and speeds vary over a wide range; yet, despite these adverse conditions, millions of thin-lined bearing inserts are giving exceptional performance in modern passenger car engines.

## Cadmium Alloys

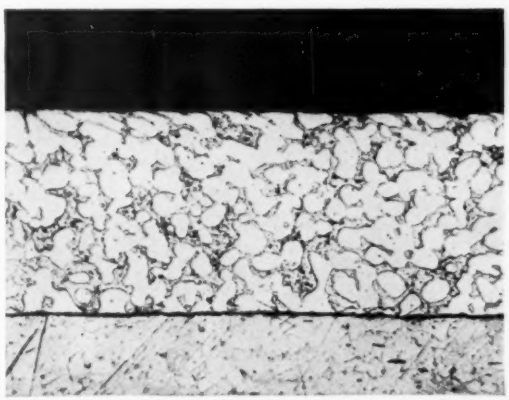
In the 1930's, when internal combustion engines were demanding a bearing material with better strength and temperature properties than were obtainable in the thick babbitts, alloys of cadmium were introduced. These metals had a cadmium content of 98.5 per cent, hardened with either nickel or silver-copper. The resultant alloys were superior to the babbitts in both mechanical strength and high temperature performance. Unfortunately, they were extremely sensitive to corrosion and were considerably more expensive. At the present time they have been supplanted by other bearing metals.

## Copper-Lead Alloys

Copper-lead bearings are today's most popular metal combination for heavy-duty service. As the name implies, the bearing alloy is a two component system in which the copper predominates. The alloy differs from those already described in that the elemental metals retain their own identity in the solid state. Microscopic examination of a copper-lead alloy will show the copper and lead as separate and independent phases as pictured in Figures 3 and 4. In the microstructures the light-toned, random copper dispersion, which is firmly brazed to the steel backing, gives the alloy its strength. The darker, lead metal interposed throughout the copper matrix provides the antifrictional properties.

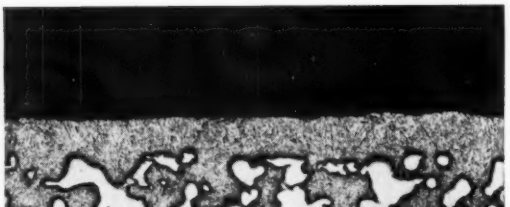
The compositions used in the copper-lead family may contain from twenty-five to forty per cent of lead. The lower lead contents produce a high-strength alloy whose antifrictional properties are not of the best. The high lead alloys, although somewhat weaker, have the best surface properties under thin-film or marginal lubrication. Silver may be added to the cast alloys, especially those of high lead content, to aid in obtaining a uniformly dispersed lead phase. When the alloys are prepared by casting, variations in technique will produce metallographic structures that will range from very fine to coarse dispersions. These structural differences are of some importance because, for equivalent lead contents, the coarse structures are weaker and more sensitive to lead corrosion even though their antifriction properties are better and they can accommodate a greater degree of abrasive contamination in the lubricant.

Copper-lead bearings may also be formed by a sintering technique. In this process, alloy pellets of copper-lead are bonded together at suitable temperatures and pressures to form the structure shown in Figure 4. The sintering process produces a high-strength alloy that has better ductility and surface



At 200 Magnifications

Figure 4 — Microstructure of a sintered copper-lead bearing. This bearing does not have a white-metal overplate.



At 100 Magnifications

**Figure 5 — Microstructure of a babbitt-impregnated copper-nickel matrix bearing. The copper-nickel areas are white; the babbitt metal dark gray.**

properties than the equivalent cast material. High lead alloys may also be produced with less possibility of lead segregation.

Copper-lead bearings have received wide acceptance even though several disadvantages exist. They are:

1. Alloys of lower lead content require hardened shafts. A minimum shaft hardness of 300 Brinell is frequently desirable.
2. The alloys are not as tolerant of misalignment as the babbitts.
3. The unalloyed lead is sensitive to corrosion.

Recognition of these disadvantages has led to the development of a hybrid copper-lead bearing that has high strength as well as good surface characteristics. This has been accomplished by the addition of a thin layer of soft-metal on the surface of the copper-lead. This surfacing metal, which is from one-to-two thousandths of an inch thick, may be seen in Figure 3. Lead-tin or lead-tin-copper alloys, whose composition may range from four to ten per cent tin with no more than two per cent copper, are employed for this purpose. The tin is necessary to impart corrosion resistance to the lead, and the copper, when present, increases the strength and wear resistance.

The white-metal overlay is a variation of the use of extremely thin linings of soft metal. In this case, however, the undersurface is a heavy-duty bearing alloy instead of the more usual steel. The white-metal layer serves several purposes in that:

1. It protects the unalloyed lead in the main portion of the bearing from possible corrosion.
2. It allows the harder copper-lead bearing to accommodate some degree of misalignment or journal ridging.
3. It makes shaft hardness requirements less stringent.
4. It improves the embeddability properties of the bearing.

## Impregnated Copper-Nickel Alloy

Copper finds use in another bearing composition the microstructure of which is pictured in Figure 5. To obtain this structure copper-nickel powders are first sintered and brazed to the steel backing; the coarse matrix (light color) is then impregnated and coated with lead babbitt (dark). The final bearing has a continuous surface of the lead babbitt.

This bearing alloy has the same excellent antifriction qualities as well as greater fatigue strength than that found in the regular babbitts. The higher fatigue strength is attributed to the copper-nickel matrix to which the babbitt is both chemically bonded and, as shown in Figure 5, mechanically interlocked. Usually when a conventional babbitt bearing fatigues, cracks penetrate directly downward from the surface toward the bond line after which they change direction and parallel the bond. This action continues until several cracks join and loosen a piece of the bearing metal. Hydrostatic pressure of the lubricant will then lift out the severed bit of metal. Such action cannot occur in the sintered structure. Fatigue cracks that develop in the babbitt are interrupted by the high strength copper-nickel matrix and are unable to unite with those from other regions. Thus, the bearing is protected from extensive metal break-out. In prolonged usage the bearing surfaces may develop numerous minute cracks but these should not be interpreted as an indication that the bearings should be replaced. The cracks are not continuous and there is no immediate danger of losing bearing metal.

## Aluminum Alloys

Aluminum, when suitably alloyed with tin, copper, silicon and nickel, has good antifriction characteristics and load-carrying capacity. Aluminum bearing alloys as first used were not satisfactory. Due to bonding difficulties, they did not have a steel backing, and when the aluminum bearing shells were thin, operating troubles were encountered because the inserts grew and became distorted in their housings. Seizure would sometimes result or the shells would be stressed beyond their elastic limit as a result of a rapid rise in temperature and become loose. The high thermal expansion of the alloy was responsible for this behavior.

Performance was improved by using thick bearing inserts in heavy housings and setting up large oil clearances. However, the factors necessary for successful service have limited aluminum bearings to diesel-powered equipment where size is not restrictive and where high bearing noise is not a serious objection.

Recent developments have shown that aluminum bearing alloys can be satisfactorily bonded to a

steel backing. Aluminum bearings are now in limited production in which aluminum is bonded to a steel shell and is finished with a thin white-metal surfacing. It is anticipated that this new aluminum bearing will find use in many automotive applications.

## Other Bearing Metals

There are a number of other bearing metals available that merit description even though they are not used in the main or connecting rods of automotive engines. Some are found in other parts of the engine. Certain bearing compositions are strictly for aircraft service while others find application in railroad, marine and industrial equipment.

*Alkali-Hardened Lead*—There is a third group of white-metal bearing alloys that has a lead content of 95 to 98 per cent. The alloys contain several per cent of tin for corrosion resistance and fractional percentages of calcium, aluminum and other metals as hardeners. Performance-wise, these metals are equivalent to the babbitts and have the added advantage of better high-temperature strength and lower cost. Unfortunately, they are sensitive to corrosion and are difficult to cast. Alkali-hardened lead bearing metals are used in railroad, marine and industrial applications.

*Bearing Bronzes*—Copper and tin form alloys that are designated as bearing bronzes. These alloys have great strength and load carrying capacity but their surface properties are so poor that accurately aligned, hardened shafts (400 Brinell) and dependable lubrication are necessary to ensure successful performance. The antifrictional properties of the bronzes have been improved by the addition of lead to a maximum of 25 per cent. The lead does not alloy with the copper-tin but is distributed throughout the structure in minute globules. A favorite composition for bushings or bronze bearing backs is an 80:10:10—copper: tin: lead alloy. Other modifications may also be employed for similar applications.

The requirements of the leaded bronzes are not as stringent as for the harder alloys. Shafts of 250 to 300 Brinell hardness will suffice for low-duty applications although the harder shafts are preferred. In automotive service bronze finds its chief application in bushings for rocker arms, wrist pins and engine accessories.

*Gridded Bearings*—To make bronze more serviceable as a bearing material, a modified structure has been developed which has the high mechanical strength of bronze in conjunction with improved antifrictional properties. This is the gridded bearing which consists of a layer of copper or leaded bronze firmly bonded to a steel backing. The surface of the copper is knurled, producing a pattern of inverted pyramids, which are then filled with babbitt or lead-tin alloy. The excess babbitt is machined off until a certain percentage of the copper-base material is exposed in the form of

*Courtesy of Federal-Mogul Corp.*

**Figure 6 — Continuous strip casting lines for the production of insert bearings.**

TABLE I
COMPARISON OF BEARING METAL PROPERTIES

| *Bearing Metal* | *Load Carrying Capacity*[b] | *Minimum Shaft Hardness Brinell* | *Fatigue Strength*[b] | *Anti-seizure*[b] | *Conformability and Embeddability*[b] | *Corrosion Resistance*[b] |
|---|---|---|---|---|---|---|
| Lead Babbitt | 5 | a | 3 | 1 | 1 | 1 |
| Tin Babbitt | 5 | a | 3 | 1 | 1 | 1 |
| Thin Babbitt Linings | 4 | a | 2 | 1 | 2 | 1 |
| Copper-Nickel Matrix | 4 | a | 2 | 1 | 2 | 1 |
| Cadmium Base | 4 | 200-250 | 2 | 1 | 1 | 3 |
| Copper-Lead | 3 | 250-300 | 2 | 2 | 2 | 3 |
| Aluminum Base | 2 | 300 | 2 | 2 | 3 | 1 |
| Copper-Lead with Overplate | 1 | 250 | 2 | 1 | 2 | 2 |
| Silver with Overplate | 1 | 300 | 1 | 2 | 3 | 1 |
| Leaded Bronze | 1 | 300 | 1 | 3 | 3 | 2 |
| Gridded Structure | 1 | 200 | 2 | 1 | 2 | 2 |

[a]Not important.
[b]Relative ratings—1 being the best.
These data based in part upon information presented by H. R. Clauser, Associate Editor, Materials and Methods Magazine, Aug. 1948.

narrow avenues that isolate a myriad of white-metal blocks. Usually the softer metal comprises at least forty per cent of the bearing surface.

By combining a high-strength metal with one of excellent surface properties a composite bearing has been produced that combines the good properties associated with both of its components. Gridded bearings have been used in some diesel engines with good results but their high cost of manufacture has restricted their application.

*Silver*—Although silver may be employed as a bearing metal without the addition of any alloying metals some compromises have to be made to circumvent its tendency toward seizure and its lack of conformability. Under most circumstances these limitations would eliminate further consideration of so expensive a metal. However, silver has excellent load carrying capacity, high fatigue strength and thermal conductivity that more than compensate for its shortcomings. Accordingly the surface characteristics of silver have been improved by the deposition of a thin layer of white-metal, usually not over 0.001 inch thick. When used in railway diesel service, the surface coating is a lead-tin alloy; for aircraft engines pure lead is employed. To protect the lead coating from corrosion, and to improve its strength and wear properties, a small percentage of metallic indium may be incorporated by thermal diffusion. The final bearing surpasses all other bearings until its overlay disappears but its high cost restricts it to aircraft service.

Silver may also be gridded and coated with babbitt in the same manner as the bronzes.

*Porous Bearings*—In a number of bearing applications where relubrication is difficult or not desired, oil-impregnated, porous bearings may be used. These bearings, which are formed by compressing and sintering metal powders, have a porosity of approximately twenty-five per cent. The pores serve as a reservoir for the lubricant which is exuded when operating friction warms the bearing. When the bearing cools, capillary action draws surplus oil back into the bearing pores.

The bearings may be made of bronze, iron or stainless steel; the choice being dependent on the loads and environment to which the bearing may be subjected. Lead or graphite may also be incorporated.

Porous bearings are cheap to produce in quantity although the initial financial outlay for dies and molds is high. They are found in many automotive accessories viz., generators, water pumps, distributors, heater motors and other parts. Powder metallurgy techniques (of which porous bearing production is a part) are also used to produce many non-bearing items—oil pump gears, filters and intricate shapes that would be prohibitive to fashion in other ways.

*Non-metallic Bearing Materials* — Bearings for special purposes may employ non-metallic materials such as nylon, wood or sapphires. They have no application to automotive service.

## Summary of Bearing Metal Properties

Comparative properties of a number of bearing materials are given in Table I; the listing being in order of increasing strength. The load-carrying capacities are greatly influenced by operating speed, temperature and the nature of the applied load, i.e., steady, pulsating or shock. It will be noted that

fatigue strength of the bearing metals increases with load-carrying capacity; these gains being made at the expense of the antifrictional or surface properties. Where high strength and good antifrictional properties are both required, the overplated copper-lead bearing is the best current choice for heavy-duty automotive service.

## BEARING MANUFACTURE

The majority of automotive insert bearings are formed in a strip process by which the bearing metal is continuously applied to a mild steel backing. Mild steel has received universal acceptance for this purpose because it is cheap, has good strength, bonds well to babbitt or copper-lead and lends itself to continuous production methods.

Bronze is sometimes used in place of steel but it has limited usage in automotive service. The metal is more expensive and of lower strength. In some cases bearing alloys of sufficient strength may be used without a supporting back. Bronze and aluminum are used in this manner in both bearings and bushings.

Connecting rods for some automotive engines may be supplied with the bearing metal cast directly into the rod housing. They suffer the disadvantage of requiring greater skill on the part of the mechanic in obtaining proper fits as clearance adjustments are obtained by the use of shims.

Although almost all of the automotive engine bearings are manufactured by continuous means, it is of interest to briefly review other methods of bearing fabrication that preceded present techniques. Where only a few bearings are required, the bearing alloy may be cast into metal molds which will serve as the bearing's back. Greater production may be obtained by casting the metal into long rotating pipes which are subsequently cut and split into bearing halves. In any of these operations control of temperature during both the casting and quenching periods is of utmost importance as variations in casting conditions may have a greater effect on the structure of the alloy than differences in alloy content.

Bearing manufacture by the continuous strip process has been developed to produce the vast volume of precision insert bearings needed by the automotive industry. The manufacturing process starts with large coils of steel which are purchased to predetermined sizes dependent upon the dimensions of the bearings to be produced. Several of the coils may be seen in the left-hand side of Figure 6. The strip, which will ultimately be the bearing back, is passed through a butt-welding machine where successive coils are joined into a continuous ribbon. Next, surface irregularities are removed and the surface cleaned prior to the application of the bearing metal. With babbitt bearings, the steel is next heated and tinned after which molten babbitt is applied, to a depth controlled by the rate of application and the speed of the strip which may range from 6 to 16 feet per minute. Side rails prevent leakage of the molten metal. After solidification, the excess babbitt is machined off.

From this point, the strip passes to blanking and coining machines that cut and shape it into bearings. Other machines in the production line form the locking lips, oil holes and grooves. Final operations consist of broaching the parting lines and bearing surfaces to close tolerances after which each bearing is individually checked to insure that all dimensions, thicknesses, parting line height and location of oil holes and grooves are correct before packaging. Sintered or cast copper-lead and the babbitt-impregnated, copper-nickel matrix bearings are formed by suitable modifications of the process described. The copper-nickel bearings have one additional and unusual step; after the copper-nickel is sintered, the strip is passed through a vacuum oven where it is impregnated with the babbitt. When copper-lead bearings are overplated, they are first formed and sized after which they are passed to a continuous electroplating machine where the soft metal is applied. These electroplating machines are capable of controlling deposit thickness to within 0.0001 inch and can plate two or three metals simultaneously in the desired ratios. Electroplating is also used to apply a protective flashing of tin to finished bearings in order to protect the backs from rusting during long storage.

## LUBRICATION AND LUBRICANTS

During normal bearing operation a lubricating oil film separates the journal from the bearing surface; strength is the only bearing property of concern. The need for antifrictional properties arises when the film ruptures and metal-to-metal contact occurs. Then the bearing alloy is of importance in avoiding welding, wiping and shaft scoring.

The possibility of metal-to-metal contact is greatest at the time an engine is started as the residual oil film on the bearing surface may not be sufficient to protect the bearing until fresh oil is delivered. Metal contact may also occur from abnormal loads and irregularities that disrupt the film during operation. Thus, it may be seen that the successful performance of a bearing is dependent on the maintenance of a thin film of oil.

The oil film is produced by the action of the journal. If the bearing and journal are considered as an oil pump the rotating shaft will act as the pump rotor and will force a small quantity of lubricant into the loaded region of the bearing by virtue of the oil adhering to its surface and to the friction within the lubricant. The viscous forces,

TABLE II

Commonly Used Lubricating Oil Additives: Purpose — Types — Uses — Functions

| *Purpose* | *Types of Compounds Used* | *Reasons for Use* | *Mechanism of Action* |
|---|---|---|---|
| Anti-oxidants or Oxidation Inhibitors | Organic compounds containing sulfur, phosphorus or nitrogen such as organic amines, sulfides, hydroxy sulfides, phenols. Metals like tin, zinc, or barium often incorporated. | To prevent varnish and sludge accumulations on engine parts. To prevent corrosion of alloy bearings. | Decreases amount of oxygen taken up by the oil thereby reducing formation of acidic bodies. Additive generally oxidizes in preference to oil. |
| Anti-corrosives Corrosion Preventatives or Catalyst "Poisons" | Organic compounds containing active sulfur, phosphorus or nitrogen such as organic sulfides, phosphites, metal salts of thiophosphoric acid, and sulfurized waxes. | To prevent failure of alloy bearings by corrosive action. To prevent corrosive attack on other metal surfaces. | Inhibits oxidation so that no acidic bodies are formed or enables a protective film to form on bearing or other metal surfaces. Chemical film formation on metal surfaces decreases catalytic oxidation of the oil. |
| Detergents | Metallo-organic compounds such as phosphates, phenolates, alcoholates. High molecular weight soaps containing metals like magnesium, barium and tin. | To keep engine surfaces clean and prevent deposits of sludge of all types. | By chemical reaction or oxidation direction, oil soluble oxidation products are prevented from becoming insoluble and depositing on various engine parts. |
| Dispersants | Metallo-organic compounds such as naphthenates and sulfonates. Organic salts containing metals, like calcium, cobalt and strontium. | To keep potential sludge forming insolubles in suspension to prevent their depositing on engine parts. | Agglomeration of fuel soot and insoluble oil decomposition products is prevented by breakdown into finely divided state. In colloidal form contaminating particles remain suspended in oil. |
| Extreme Pressure Agents | Phosphorus compounds like tricresyl phosphate, sulfurized lard oil, halogenated compounds. Lead soaps such as lead naphthenate. | To prevent unnecessary wear of moving parts as well as scuffing or scoring. | By chemical reaction film is formed on metal surfaces which prevents welding or seizure when lubricating oil film is ruptured. |
| Rust Preventives | Amines, fatty oils and certain fatty acids. Halogenated derivatives of certain fatty acids. Sulfonates. | To prevent rust in new and overhauled engines during storage or shipment. | Preferential wetting of metal surfaces through added adhesiveness. |
| Pour Point Depressants | High molecular weight condensation products, such as phenols condensed with chlorinated wax. Methacrylate polymers. | To lower pour point of lubricating oils. | Wax crystals in oil coated to prevent growth and oil absorption at reduced temperatures. |
| Viscosity Index Improvers | Polymerized olefins or iso-olefins. Butyl polymers, cellulose esters, hydrogenated rubber. | To lower rate of change of viscosity with temperature. | Improvers are less affected by temperature change than oil. They raise viscosity at 200°F. more in proportion than at 100°F. |
| Foam Inhibitors | Silicones. | To prevent formation of stable foam. | Enables foam to break up quickly and disappear. |

which wedge the fluid into the high-load region between the two surfaces, will cause a pressure to be created in the film that will keep the surfaces apart. At the instant of separation, the film is imperfect and there is a borderline condition known as thin-film lubrication. As more oil is forced into the load zone the film will thicken and "float" the journal. Advantage is taken of this action in large steel mill bearings where an external oil pump is used to float the shaft before rotation is started. This is done to protect the bearings from wiping.

Consideration of oil-film formation has shown that the viscosity of the lubricant is of utmost importance. If too low, the film will be thin; if too high, friction losses within the lubricant will be considerable and oil film formation will be hampered.

The primary functions of the lubricant are:

1. To eliminate friction (metal-to-metal).
2. To act as a coolant and heat transfer medium.
3. To act as a sealing agent.

Furthermore, the modern lubricant through the addition of other materials, known as additives, is able to perform a number of secondary functions that are of importance to bearing performance. They are:

1. To prevent oil contaminants or deposit-forming materials from interfering with engine operation.
2. To prevent rusting of ferrous parts.
3. To prevent corrosive wear.

The operating range of the lubricant has been extended by the use of pour depressants and viscosity index improvers. Typical additive compounds and their functions are shown in Table II. Many are metallo-organic materials that impart qualities not present in the crude oil or the refined stock.

## BEARING LIFE

The bearing manufacturers have expended considerable research on the design and development of automotive insert bearings. They have endeavored to reckon with all the factors necessary to give the bearing a potentially long and satisfactory life. Approximate bearing life that may be anticipated for several types of service are shown in Table III.

TABLE III

Anticipated Bearing Life for Various Services

| *Service* | *Bearing Life, Hours* |
|---|---|
| Aircraft Engines | 2,000 |
| Passenger Cars | 3,000 |
| Trucks | 4,000 |
| Marine and Rail | 15,000 |
| Stationary | 25,000 |

The considerable difference in estimated bearing life between aircraft and stationary service is due to the magnitude and duration of the peak loads. Bearings subjected to low unit pressures with little or no peak demands will enjoy long life while the life of those bearings which operate at or near their maximum load-carrying capacity will be short. For example, the soft babbitt bearings used in many stationary power plant engines give years of service while the high-strength, silver, master-rod bearings in aircraft engines are relatively short lived.

Automotive bearing life, in terms of mileage, will approximate 75,000 and 150,000 miles for cars and trucks respectively. These values are not necessarily top limits. Unfortunately, however, there are too many instances in which bearing performance falls far short of these mileage figures because of malpractices.

### Factors Affecting Bearing Performance

Optimum bearing performance is dependent upon the following factors:

1. Proper bearing installation.
2. Good preventive maintenance.
3. Reasonable vehicle operation.

### Installation

Undoubtedly bearing installation has the greatest influence on subsequent bearing life. Errors at this point are chiefly responsible for premature failure—a condition that so often follows the overhaul of an engine.

To insure proper bearing installation and to avoid premature bearing failure, the conscientious mechanic will follow the instructions given in the engine service manuals and will heed the precautions listed in Table IV.

TABLE IV

Precautions to Observe When Installing Engine Bearing Inserts

1. Clean all parts. Dirt is a major cause of bearing distress.
2. Measure, do not guess. Be sure the proper size bearings are being installed.
3. Fit. Be sure the bearing inserts are snug in their caps. Check their spread and crush. Do not file the parting edges. Do not use shims unless they are specified.
4. Journal Condition. Dress crankshaft to a fine, lapped finish. Be sure that all wear ridges have been removed. Do not attempt to install bearings on out-of-round or hour-glass-shaped journals.

Figure 7 — Completely wiped bearing. The distress was so severe that the steel backing had plastically deformed.

Figure 8 — Bearing surface that had been scored by foreign particles in the lubricating oil.

5. Misalignment. Check alignment of crankshaft and connecting rods.
6. Torque. Set up bearing caps evenly with a torque wrench.
7. Lubrication. Be sure all oil ways are clean and that the oil holes are open when the bearings are installed. Oil new inserts with SAE-50 grade oil.
8. Be sure the sump, oil galleries, filters, coolers, etc., are full of oil before starting the engine.

## Maintenance

Once an automotive engine is in service a good preventive maintenance program is necessary. Good maintenance today does not require that the operator drain the engine crankcase every night, but does demand a relubrication schedule that is in keeping with the environment and operation. The chief concern is to keep the engine clean. Vehicles used in gravel pits or quarries will be exposed to severe dust conditions that will necessitate more frequent oil drains and replacements of air and oil filter elements than would paved-road operation. Local delivery service may require frequent drain periods in order to remove fuel and combustion products. These contaminants are most annoying in cold-weather operation when they may lead to low-temperature sludges if they are not removed.

Good maintenance procedures will demand that the engine be in proper operating condition and that only quality fuels and lubricants from reputable suppliers be used. The same care will be extended to the selection of replacement bearings. Economies rarely result from the purchase of second-rate products.

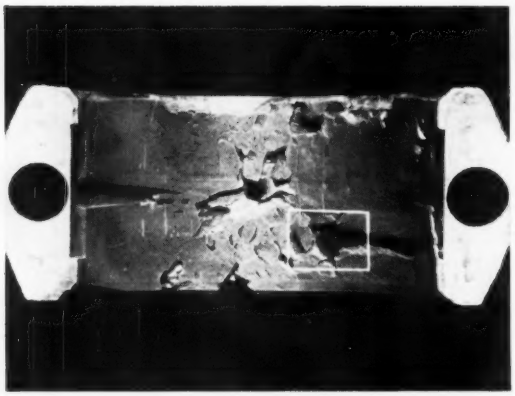
## Operation

Bearing life is dependent upon the manner in which the engine is operated. Continuous high-speed driving will produce high inertia and centrifugal loads that can lead to the "shelling out" of metal from the lower half of the connecting-rod bearings. Similar troubles will be encountered when the engine is used to brake the vehicle in downhill descents because at such times, there is little combustion gas pressure to oppose the upward movement of the piston.

The driver may also promote bearing distress by allowing the engine to "lug", i.e., letting the engine operate at lower-than-normal speeds rather than downshifting at a time when the vehicle is losing road speed. Bearing metal break out will

At 125 Magnifications

**Figure 9 — Section of a babbitt-impregnated, copper-nickel matrix bearing showing the embedment of foreign particles.**



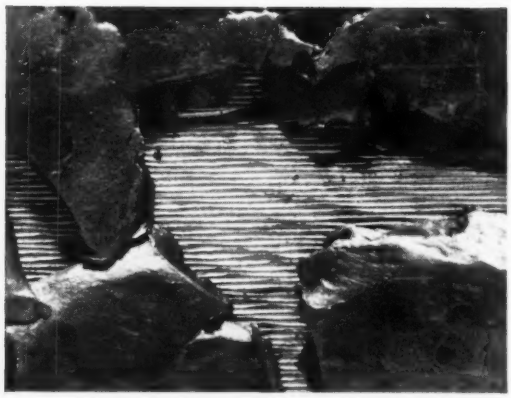


Figure 10

Upper View — Bearing surface which failed from poor bond and metal fatigue.

Lower View — Closeup of broken-out area — note sharpness of the breaks and the tool marks on the steel surface.

occur in the upper halves of the connecting-rod bearings because the inertia forces will be insufficient to counteract the high combustion pressures. The lower engine speeds will also slow the oil pump and reduce the quantity of lubricant delivered to the bearings.

There are other driving habits that will have a pernicious effect on bearing life. Rapid, cold-engine, jack-rabbit starts, before an adequate supply of oil has been delivered to the bearings may cause metal-to-metal contact. The innocent habit of riding the clutch will laterally displace the engine crankshaft against the thrust face of the main bearing flange and the continuous rubbing will result in early failure of this bearing.

## BEARING FAILURE

The day is past when engine bearing failures could be attributed to poor bearing metal, to a defective bond or to an inferior lubricant. Today, bearing failures may be diagnosed and the necessary corrective action taken, providing the specimen has not been completely mutilated as shown in Figure 7.

Generally, bearing failures will assume one or more of the following forms.

1. Surface Distress
   a. Wear
   b. Particle embedment and scoring
   c. Wiping
2. Metal Breakout
   a. Poor bonding
   b. Fatigue
3. Corrosion

### Surface Distress

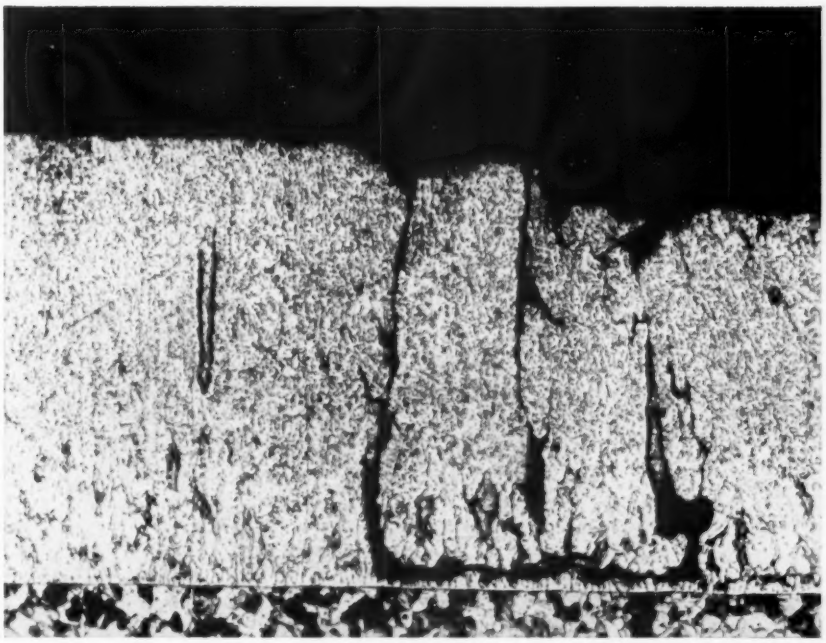
A reasonable amount of bearing surface wear is to be expected during operation. The wear is caused by microscopic particles of abrasive material which cannot be economically removed from the lubricant. In the event that this material is allowed to build up, wear will be accelerated. Usually, it is the larger foreign particles that promote serious damage as they attempt to pass through the bearing clearance. Many times these particles will plow their way across the bearing surfaces as shown in Figure 8. Other times, they will circumferentially score the surface. Where the bearing metal is soft, the particles may embed themselves as illustrated in the bearing section in Figure 9. The extent of contamination may be appreciated by referring to the new bearing section in Figure 5. Where the bearing surface has been displaced by dirt, the soft metal will form a crater or ridge around the particle or furrow. The raised portions may then rub against the journal producing a mottled bearing surface characteristic of dirty conditions. High shaft wear may result if the bearings engulf too much abrasive material.

When the bearing surface has experienced complete wiping at low mileage, the installation procedures outlined in Table IV may have been ignored; at higher mileages, any of the recognized types of bearing distress could have initiated the failure.

### Metal Breakout

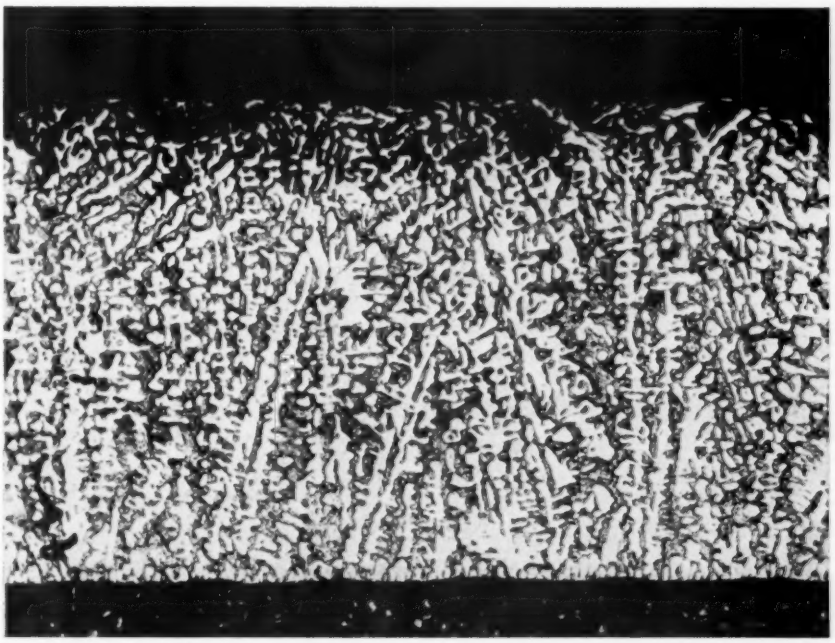
The breaking away of the lining metal of a bearing generally occurs when the applied stresses have exceeded the fatigue strength of the bearing alloy. This condition may arise in a number of ways.

The classic example is poor bonding; a condition which seldom arises in modern bearings. The bearing failure shown in the upper view of Figure 10 is typical. A closeup of the distressed region is shown in the lower view. Note the direct dow-



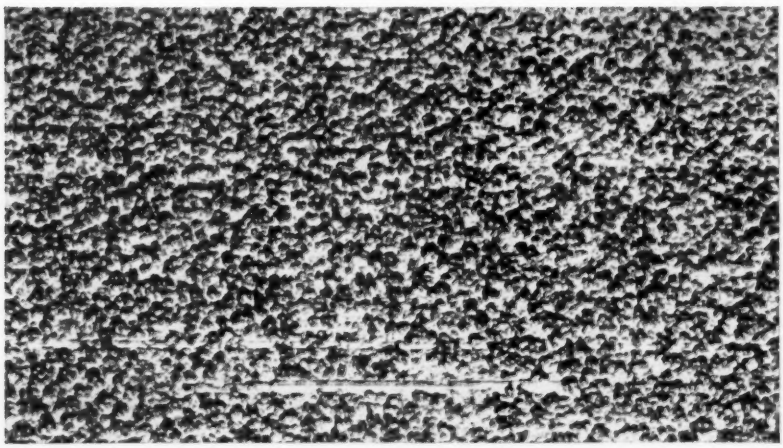
At 100 Magnifications

Figure 11 — Fatigue cracks in a fine-structured, copper-lead bearing. A large piece of the bearing metal has broken loose.



At 100 Magnifications

Figure 12 — Corroded, medium-structure, copper-lead bearing. The lead phase (dark gray) has been selectively removed from the upper portion of the alloy.



At 10 Magnifications

Figure 13 — Pitting attack on the surface of an alkali-hardened lead bearing.

ward penetration of the cracks and the cleanliness of the machined steel back. There is no evidence of bearing metal adhering to its surface. The strength of the bearing was concentrated in the relatively weak lining metal which was unable to carry the load and ultimately fatigued. It may be seen that the alloy had plastically deformed along the sides of the cap but there is no indication of a lubrication failure; the metal had not wiped.

Any condition that produces repetitive overload on the bearing surface may result in metal fatigue and breakout. A bent connecting rod, a ridged or "cammed" journal, a bit of hard dirt under the bearing insert or other misalignment that will overload a portion of the surface will promote the localized breaking away of the bearing metal lining. In a similar manner, severe or abnormal operating conditions (high-speed driving or lugging) will cause particular bearing parts to fatigue. Fatigue failure in a copper-lead bearing is shown in Figure 11. This structure shows the same vertical fatigue cracks as were present in the poorly bonded babbitt.

## Corrosion

The only corrosion-sensitive bearing material in current automotive service is copper-lead. However, its corrosion sensitivity has not proven to be a problem as today's engine oils are extremely stable under normal operating conditions.

When corrosion occurs in copper-lead bearings, the lead phase is selectively removed, as shown in Figure 12, and a lacy network of copper remains. With continued use, the unsupported copper will often compact and wiping or fatigue will ultimately result. Many of the reported cases of corrosion with copper-lead bearings have actually been fatigue failures as pictured in Figure 11. This confusion in identification has been brought about by misinterpretation of the surface condition. Where this doubt exists, microscopic examination of the bearing structures will clearly show the failure mechanism. Referring to Figures 11 and 12, where fatigue has occurred, metallic lead is still present at the bearing surface; in the case of corrosion the lead is absent.

Copper-lead corrosion may be prevented by coating the surface with a lead-tin overlay. If this coating should be punctured or scored, corrosion can occur wherever the lead is exposed.

Corrosion may also take place as a general removal of surface metal as illustrated by the pitting attack shown in Figure 13. This occurred on the surface of an alkali-hardened lead bearing. A failure of this sort would not be anticipated in automotive service.

## CONCLUSION

The importance of the part that bearings play in precision mechanisms can best be appreciated by reference to the voluminous literature that is currently available on bearing materials, their behavior and application. While many of these articles are of a highly technical nature, there is an ever increasing number that are devoted to the needs of the automotive service man. Credit for many of these articles is due to the bearing manufacturers who have also, through their own publications, endeavored to instruct those persons who have a practical interest in the handling and installation of bearing inserts. The bearing manufacturers are to be further complimented for their unceasing search for the perfect bearing material, which, like the philosophers' stone, is still out of reach.



Printed in U. S. A. by
Salley & Collins, Inc.
305 East 45th Street
New York 17, N. Y.

# LONGER LIFE for Chassis Parts

## . . . begins with the use of TEXACO MARFAK

**MORE THAN 500 MILLION POUNDS OF TEXACO MARFAK HAVE BEEN SOLD**

WHEN *Texaco Marfak* goes into a chassis bearing, it goes in to *stay* — for extra hundreds of miles of protection. That's because *Texaco Marfak* is both adhesive and cohesive. The roughest pounding won't jar it out; the heaviest loads won't squeeze it out. Chassis parts last longer and maintenance costs come down because *Texaco Marfak* assures this longer lasting protection against wear and rust.

In wheel bearings, *Texaco Marfak Heavy Duty* gives the same superior wear- and rust-protection. And the fact that it won't leak onto the brakes is a safety advantage. No seasonal change is required.

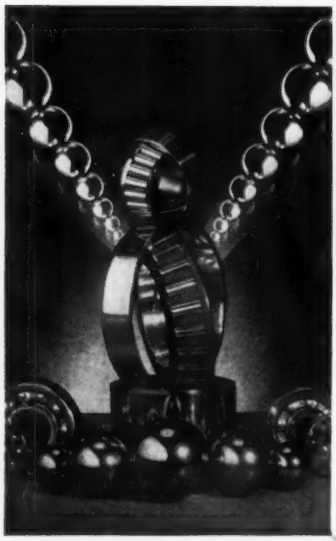
Let a Texaco Lubrication Engineer help you build up your operating efficiency and bring down your maintenance costs. Just call the nearest of the more than 2,000 Texaco Distributing Plants in the 48 States, or write The Texas Company, 135 East 42nd Street, New York 17, N. Y.

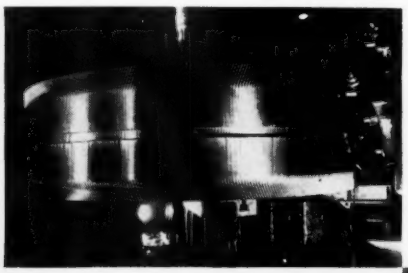
TEXACO

**TEXACO Lubricants and Fuels**

FOR THE TRUCKING INDUSTRY

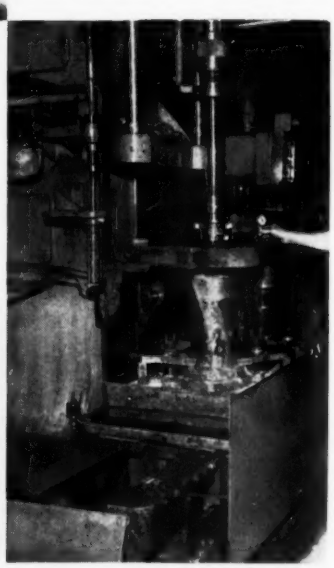
# *These typical examples show that . . .*





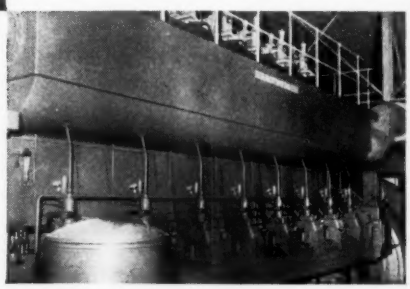
**CATERPILLAR TRACTOR COMPANY** assures uninterrupted hydraulic machine operation with *Texaco Regal Oil (R & O).*

**FALK CORPORATION** maintains accuracy in hobbing big gears by using *Texaco Sultex Cutting Oil.*



**POTASH COMPANY OF AMERICA** has kept Diesel operating costs low for 20 years with *Texaco Ursa Oil.*

**HOOVER BALL & BEARING COMPANY** gets better finish by grinding with a *Texaco Soluble Oil* emulsion . . . output is up, costs down.



# YOU CAN INCREASE OUTPUT, REDUCE YOUR UNIT COSTS—

Whatever you make, wherever your plant is located, no matter what your machinery or equipment . . . Texaco stands ready to help you turn out more of your product at a lower unit cost.

Use the Texaco Industrial Lubricants made for your particular needs. Call on Texaco Lubrication Engineering Service for advice and practical help that goes far beyond mere lubricant recommendations.

Reach for your phone now and call the nearest of the more than 2,000 Texaco Distributing Plants in the 48 States, or write:

The Texas Company, 135 East 42nd Street, New York 17, N. Y.

**THE TEXAS COMPANY • TEXACO PRODUCTS • DIVISION OFFICES**

**ATLANTA 1, GA.**, 864 W. Peachtree St., N.W.
**BOSTON 17, MASS.**.....20 Providence Street
**BUFFALO 3, N. Y.**.....14 Lafayette Square
**BUTTE, MONT.**.....220 North Alaska Street
**CHICAGO 4, ILL.**.....332 So. Michigan Avenue
**DALLAS 2, TEX.**.....311 South Akard Street
**DENVER 5, COLO.**.....1570 Grant Street
**HOUSTON 1, TEX.**.....720 San Jacinto Street
**INDIANAPOLIS 1, IND.**, 3521 E. Michigan Street
**LOS ANGELES 15, CAL.**....929 South Broadway
**MINNEAPOLIS 3, MINN.**....1730 Clifton Place
**NEW ORLEANS 6, LA.**....919 St. Charles Street
**NEW YORK 17, N. Y.**.....205 East 42nd Street
**NORFOLK 1, VA.**....Olney Rd. & Granby Street
**SEATTLE 11, WASH.**..... 1511 Third Avenue

**Texaco Petroleum Products are manufactured and distributed in Canada by McColl-Frontenac Oil Company Limited.**